

1. A fuel injector comprising:
 - a nozzle body defining a needle bore axially extending between a needle guide and a nozzle body defining a nozzle seat, said needle guide axially interrupted into upper and lower needle guide portions by a circumferential fuel inlet control volume having first upper and first lower metering edges, said nozzle body defining a fuel inlet passage communicating with said fuel inlet control volume; and
 - an elongated needle valve received in said needle bore for axial reciprocation therein between a closed position and an open position, said needle valve having oppositely disposed tip and head ends axially separated by a needle valve shank, said tip end being disposed adjacent to and configured to engage said nozzle seat when said needle valve is in the closed position, said head end having an outside surface received within said needle guide and axially interrupted into outside surface upper and lower portions by a first control volume having second upper and second lower metering edges, said head end defining a fuel passage communicating between said first control volume and said needle bore axially below a bottom edge of said outside surface lower portion,
- the needle guide having a greater diameter than the nozzle seat to provide a differential area for hydraulically moving the needle valve away from engagement with said nozzle seat, the fuel inlet control volume being connected to receive periodic high pressure pulses of fuel for opening the needle valve against a closure bias,
- when the needle valve is in said closed position, said first upper metering edge and said second lower metering edge are axially spaced to define a circumferential fluid flow clearance and said lower needle guide portion axially overlaps with said outside surface lower portion, said axial overlap being greater than or equal to an axial dimension of said fluid flow clearance,

whereby initial movement of said needle valve is produced by fuel flowing through said fluid flow clearance and said fuel passage to said needle bore.

5 2. The fuel injector of claim 1, wherein said head end outside surface and said needle guide are complementary generally cylindrical surfaces.

10 3. The fuel injector of claim 1, wherein needle valve movement away from said closed position restricts fluid flow between said fuel inlet control volume and said needle bore by reducing said fluid flow clearance.

15 4. The fuel injector of claim 1, wherein needle valve movement away from said closed position interrupts fluid flow between said fuel inlet control volume and said needle bore by closure of said fluid flow clearance.

20 5. The fuel injector of claim 1, wherein axial movement of said needle valve greater than said axial overlap closes said fluid flow clearance and opens a direct fluid flow path between said fuel inlet control volume and said needle bore when said outside surface portion bottom edge moves axially above said first lower metering edge.

25 6. The fuel injector of claim 1, wherein said axial overlap is at least twice the axial dimension of said fluid flow clearance.

7. The fuel injector of claim 1, wherein said axial overlap is approximately three times the axial dimension of said fluid flow clearance.

8. A fuel injector comprising:

a nozzle body defining an elongated needle bore extending between a nozzle seat and a longitudinally spaced needle guide and including a nozzle body enclosing the needle bore below the nozzle seat
5 and defining spray holes communicating with the needle bore, said needle guide interrupted by a circumferential fuel inlet control volume to define an outer metering ring intermediate said fuel inlet control volume and said nozzle seat, said outer metering ring having an internal metering surface between axially spaced upper and lower metering
10 edges;

a needle valve axially extending between a tip and a head, said needle valve disposed in the needle bore with a guide surface of said head received within said needle guide to control axial movement of the needle valve within the needle bore between a closed position where
15 said tip is in engagement with the nozzle seat and an open position with a predetermined axial separation of said tip from said nozzle seat, said guide surface interrupted by a first control volume to define an inner metering ring intermediate said groove and said tip, said inner metering ring having an external metering surface between axially spaced upper
20 and lower metering edges, said needle valve defining a fuel passage communicating between said first control volume and said needle bore axially below said inner metering ring;

a pressure adjusting spring biasing the needle valve downwardly into engagement with the nozzle seat;

25 the needle guide having a greater diameter than the nozzle seat to provide a differential area for hydraulically opening the needle valve against the bias of the closure spring;

the fuel inlet control volume being connected to receive periodic high pressure pulses of fuel for opening the needle valve against the bias
30 of the closure spring and for supplying fuel for injection through the spray holes;

the inner metering ring, with the needle valve in its closed position, being received within the outer metering ring with the inner metering ring lower metering edge below the outer metering ring upper metering edge by an axial overlap greater than an axial clearance

5 between the inner metering ring upper metering edge and an upper terminus of said fuel inlet control volume,

wherein said needle valve is initially opened by fuel flowing through a first fluid flow path defined by said axial clearance, said groove and said fuel passage into said needle bore below said inner metering ring.

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9. The fuel injector of claim 8, wherein axial movement of said needle valve away from said closed position closes said axial clearance, interrupting said first fluid flow path prior to opening a second fluid flow path.

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10. The fuel injector of claim 8, wherein a second fluid flow path is opened upon axial movement of said needle valve away from said closed position an axial distance greater than said axial overlap, said second fluid flow path communicating directly between said fuel inlet control volume and said needle bore.

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11. The fuel injector of claim 8, wherein a second fluid flow path is opened upon axial movement of said needle valve away from said closed position an axial distance greater than said axial overlap, said second fluid flow path communicating directly between said fuel inlet control volume and said needle bore, said first fluid flow path closing before opening of said second fluid flow path.

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12. The fuel injector of claim 8, wherein said axial overlap is at least twice said axial clearance.

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13. The fuel injector of claim 8, wherein said axial overlap is approximately three times said axial clearance.

14. A fuel injector comprising:

5 an nozzle holder body defining an elongated needle bore extending between a nozzle seat and a needle guide and including a nozzle body enclosing the needle bore below the nozzle seat and defining spray holes communicating with the needle bore, said nozzle holder body defining a fuel inlet passage communicating with said needle bore at an
10 axial position corresponding to said needle guide;

 a needle valve having a valve stem extending between a tip configured to engage said nozzle seat and a head having a diameter greater than said stem, said needle valve received in said needle bore with said tip adjacent said nozzle seat and said head surrounded by said
15 needle guide, said needle valve defining a fluid passage radially inwardly through an outside surface of said head and axially downwardly toward said valve stem, said needle valve axially moveable within said needle bore between a closed position in which said tip is sealingly engaged with said nozzle seat and an open position in which said needle valve is
20 moved away from the nozzle seat to permit fuel injection through the spray holes;

 wherein said needle valve cooperates with said nozzle holder body to define a variable volume second control volume surrounding said valve stem, said fuel inlet passage is connected to receive periodic high
25 pressure pulses of fuel for delivery to the second control volume to hydraulically open the needle valve against said bias, alternative pilot and primary fuel flow paths being defined between said fuel inlet passage and said second control volume, said pilot fuel flow path extending from said fuel inlet passage through said fluid passage, said primary fuel flow
30 path communicating directly between said fuel inlet passage and said second control volume, said pilot fuel flow path being open when said needle valve is in the closed position and for a pre-determined initial

axial movement of said needle valve away from said nozzle seat and opening said primary fuel flow path requires axial needle valve movement through an intermediate valve position in which said pilot fuel flow path is closed.

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15. The fuel injector of claim 14, wherein initial movement of said needle valve is produced by fuel flow through said pilot fuel flow path.

10 16. A method for controlling the rate of injection through a fuel injector of the type having an nozzle holder body defining a needle bore and a needle valve received for axial reciprocation in the needle bore between a closed position in which fuel is not injected and an open position in which fuel is injected, said method comprising the steps of:

15 providing a pilot fuel flow path open only during a predetermined initial axial movement of said needle valve away from said closed position;

20 providing a primary fuel flow path open only after said needle valve has moved through an intermediate axial position beyond said initial axial movement, said pilot fuel flow path being closed in said intermediate axial position.

17. The method of claim 16, wherein said step of providing a pilot fuel flow path comprises:

25 constructing the nozzle holder body and needle valve to physically block said pilot fuel flow path at axial positions of said needle valve corresponding to axial movement greater than said predetermined initial axial movement.